

Trend analysis of extreme rainfall in Cikapundung Watershed, West Java, Indonesia

Unggul Handoko^{1*}, Muh Fakhrudin², Apip², Hidayat², Turmudi², and Endra Triwisesa²

¹Research Center for Climate and Atmosphere, National Research and Innovation Agency (BRIN), KST Samaun Samadikun, Jl. Cisitua Sangkuriang, Bandung 45363, Indonesia

²Research Center for Limnology and Water Resources, National Research and Innovation Agency (BRIN), KST Soekarno, Jl. Raya Bogor Km. 46, Bogor 16911, Indonesia

Abstract. Bandung is one of the areas prone to flood disasters in Indonesia. The areas frequently affected by flooding are located around the Cikapundung Watershed. Floods are triggered by several factors, namely: rainfall, changes in land use, as well as geological and morphological conditions. The aim of this research is to analyze rainfall in the Cikapundung watershed to see whether there is an increase in extreme rainfall from 1977-2022. The method used in this research is first to test the homogeneity of rainfall over 45 years. Next, the extreme rainfall indices and the trend of each wet extreme rainfall indices were calculated using the Mann-Kendall test. The research results show that statistically, of the 20 indices analyzed, only one indices experienced a significant downward trend, namely the Rx5day indices at Kayu Ambon station. Other indices show a p-value of more than 0.05, which means statistically there is no trend, either an upward trend or a downward trend.

1 Introduction

There are many natural disasters in the form of hydrometeorological disasters in Indonesia. These disasters include droughts, floods and landslides. From 2010 to 2020, disasters in Indonesia are dominated by hydrometeorological events such as floods, cyclones and landslides, which are related to climate change. Over the past ten years, the trend of hydrometeorological disasters has increased [1]. Furthermore, other research results based on recapitulation data obtained from The National Agency for Disaster Countermeasure (Indonesian: Badan Nasional Penanggulangan Bencana) in 2018, there were 2,572 natural disaster events throughout Indonesia. Of these, hydrometeorological disasters dominated the disaster events, which amounted to 2,073 events or around 80.59% [2].

Flooding is a problem that occurs in almost all watersheds in the world. Floods and landslides are two of the most frequent hydrometeorological disasters in the world; they are caused by extreme rainfall and exacerbated by climate change. These disasters result in enormous losses in terms of lives and property, and in many area they are becoming more frequent and intense. Effective risk assessment and disaster management are essential to reduce their impact and protect vulnerable people [3], [4]. Indonesia experienced the second

* Corresponding author: unggulhandoko@gmail.com

highest number of floods and landslides after China. Estimated economic losses from floods in 2016 amounted to US\$ 59 billion in 31 countries and 4,731 deaths. World annual disaster statistics also state that the average deaths due to floods are 5,709 per year (2006-2015)[5].

The Cikapundung watershed has a long history of hydrometeorological disasters. Flooding has become a major and prolonged challenge in this region. In 1808, the capital city of Bandung was moved from Dayeuhkolot to the northern part of Upper Citarum to avoid damage from flooding. Floods that have occurred since January 23, 2020 have hit five sub-districts in Bandung Regency, West Java with an affected population of 11,659 households or 40,844 people. Material losses due to flooding in Bandung Regency also increased to 7,638 submerged houses, 13 submerged schools and 32 submerged places of worship [6]. This flood disaster is caused by several parameters, including high rainfall intensity and changes in river watersheds, so it requires the implementation of short-term and long-term solutions to overcome it. Therefore, The Cikapundung watershed was chosen as the study area in this research. Research on climate change in the Cikapundung watershed is very important for understanding trends in extreme rainfall conditions. The characteristics of extreme rainfall will be analyzed using the developed climate indices by the Climate Change Detection and Indices Expert Team (ETCCDI). This research aims to analyzing the characteristics of extreme rainfall in the Cikapundung watershed from 1977-2022.

2 Methodology

2.1 Study area

Cikapundung River is one of the rivers that divides Bandung City through 9 sub-districts covering 13 villages. The study area map is presented in Fig 1.

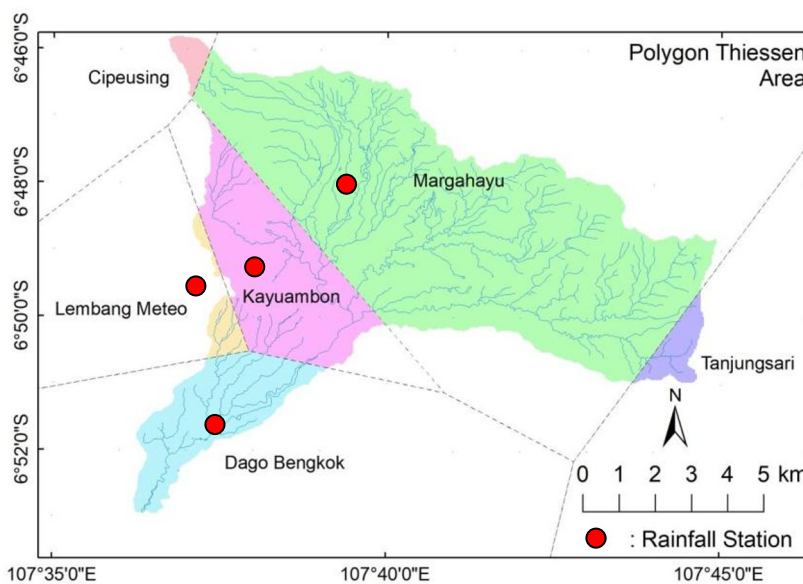


Fig. 1. Map of the study area

2.2 Methods

This study analysed historical rainfall data in the Cikapunding watershed for 45 years to assess its consistency and detect patterns or trends. There are 6 rainfall stations in the Cikapunding watershed. Most of the rainfall data obtained for this study was collected from automatic rain gauges using a tipping bucket mechanism. These gauges measure data with a sensitivity of 0.5 mm for each tip. Rainfall data was obtained from the Meteorology, Climatology and Geophysics Agency, the Ministry of Public Works and Housing and from the West Java Provincial Water Resources Office. In this study, the variables tested were the amount of rainfall received each year.

2.2.1 Homogeneity test

The first step before testing the trend of extreme rainfall is quality control and homogeneity test of rainfall data. The homogeneity test is used to detect whether any significant changes have occurred over time. These changes can be natural (global climate influence) or human intervention. Non-natural changes can be caused by various things such as relocation, environmental changes, tools used, or observation methodology [7]. The homogeneity test in this study is in accordance with research [8], namely the Pettitt test, Buishand range test (BRT), Von Neumann Ratio test (VNR) and The Standard Non Homogeneity Test (SNHT). A data series is said to be homogeneous if the p-value > 0.05 . The results of the four homogeneity tests are then used to determine the category whether it can be used for further analysis or not. The categories are [9]:

- a. Category A (Useful): If there is a maximum of one test that states that it is not homogeneous, then the data can be used for further analysis.
- b. Category B (Doubtful): If there are two tests that state that they are not homogeneous, then the data must be checked carefully before being used for further analysis.
- c. Category C (Suspect): If there are three or all tests that state the data is not homogeneous, then the data can be ignored.

2.2.2 Extreme rainfall trend analysis

The next step is to calculate the extreme rainfall indices and analyze the trend in each extreme wet rainfall indices using the Mann Kendall test. Extreme rainfall parameters use indices that have been developed by the Expert Team for Climate Change Detection and Indices (ETCCDI) and have been widely used [10], [11], [12], [13] and to calculate the indices using RCLimDex software. In this study, the analyzed rainfall is wet extremes, therefore 5 indices were selected from 11 ETCCDI extreme rainfall indices, namely:

- a. Rx1day (Max 1- day precipitation amount) i.e. the maximum amount of one-day precipitation in 1 year (mm).
- b. Rx5day (Max 5-day precipitation amount) i.e. the maximum amount of rainfall on five consecutive days in a year (mm).
- c. R50mm (Very heavy precipitation days) is the number of days in a year with rainfall equal to 50 mm per day, the value of nn is determined by the user, in this study the nn used is 50 mm.
- d. R95p (Very Wet Days) is the total amount of annual rainfall with rainfall above the 95th percentile in mm.
- e. R99p (Extremely Wet Days) is the total amount of annual rainfall with rainfall above the 99th percentile in mm.

An indice is said to have a statistically significant trend if the p value is smaller than 0.05, and vice versa. If the value is greater than 0.05 then it can be said that there is no trend.

3 Result and discussion

3.1 Homogeneity test

The homogeneity test constitutes a statistical analysis employed to ascertain whether two or more datasets exhibit identical or homogeneous variance. This examination holds significant importance within statistical analysis that presupposes the homogeneity of variance among various groups. The advantage of conducting the homogeneity test lies in its ability to guarantee the validity of the analytical results and to enhance the precision of data interpretation.

The results of the homogeneity test of the 6 rainfall stations used in this study can be presented in table 1 below.

Table 1. Result of homogeneity tes.

Rainfall Station	p-Value				Remarks
	Pettitt test	SNHT	BRT	VNR	
Lembang	0.665	0.384	0.667	0.856	Useful
Dago	0.341	0.531	0.246	0.487	Useful
Tanjungsari	0.212	0.830	0.863	0.715	Useful
Margahayu	0.688	0.478	0.269	0.006*	Doubtful
Kayu Ambon	0.706	0.117	0.094	0.779	Useful
Cipeusing	<0.0001*	0.001*	0.000*	0.029*	Suspect

*p-value is less than 0.05, which means the rainfall data is not homogeneous

Based on Table 1, we can know that of the six rainfall stations that were tested for homogeneity, four rainfall stations can be used for further analysis, namely the Lembang, Dago, Tanjungsari, and Kayu Ambon. The rest cannot be used for further analysis because it is in the doubtful category, namely the Margahayu rainfall station, and the suspect category, namely the Cipeusing rainfall station. This is by research conducted by [14], which states that inhomogeneous series should be excluded before any trend analysis could be conducted. Because, inhomogeneous data can obscure true climatic signals and patterns, leading to potentially biased conclusions in climate and hydrological studies [15].

3.2 Extreme rainfall trend analysis

An extreme rainfall index is a statistical measure used to analyze rainfall events of unusually high intensity or duration within a region. This index is often used to monitor climate change and understand rainfall patterns that can trigger disasters such as floods or landslides. Some commonly used indices include the number of days with rainfall exceeding a certain threshold (e.g. 50 mm per day), the maximum amount of rainfall in a given period, or the duration of consecutive extreme rainfall. Information from these indices is important for disaster risk mitigation planning, water resources management, and climate adaptation policies.

The results of the senslope calculation and trend analysis using Mann-Kendall can be presented in table 2 below. Table 2 summarizes the trend analysis of extreme rainfall from four rainfall stations in the Cikapundung watershed. There are five extreme rainfall indices analyzed, namely Rx1day, Rx5day, R50mm, R95p, and R99p. Based on the table, it can be seen that the statistically significant trend is only one indice from a total of 20 indices analyzed, namely the Rx5day indices at the Kayu Ambon rainfall station. Rx5day at the Kayu Ambon shows a downward trend. The rest of the indices shows a p-value of more than 0.05, which means statistically there is no trend, either an upward trend or a downward trend. So from the trend analysis of the extreme rain indices in the Cikapundung watershed, it can be said that in this region there is no trend in the extreme rain indices. The results of this study are in line with research conducted by [16], which states that the extreme rainfall indices does not show a significant trend overall, but there is a trend toward wet conditions in Indonesia. Research conducted by [17], also revealed that on Madura Island most of the rainfall stations analyzed did not show a significant trend.

Table 2. Result of tend analysis.

Rainfall Station	Statistic Parameters	Extreme Rainfall Indices				
		rx1day	rx5day	R50mm	R95p	R99p
Dago	Sens Slope	-0.166	-0.011	-0.007	-1.993	-0.742
	p-value	0.644	0.982	0.843	0.502	0.647
Lembang	Sens Slope	0.143	0.315	0.022	2.827	2.484
	p-value	0.887	0.763	0.671	0.521	0.185
Tanjungsari	Sens Slope	0.432	0.52	-0.011	1.775	0.217
	p-value	0.734	0.749	0.936	0.856	0.968
Kayu Ambon	Sens Slope	-0.086	-2.28	-0.036	-11.24	-3.232
	p-value	0.857	0.011*	0.532	0.133	0.241

*p-value is less than 0.05, which means that the trend is significant

This finding contrary to research on how floods in Batanghari Watershed, Jambi Province, Indonesia are affected by a extreme rainfall indices. The study demonstrated that within the same period, there was a correlation between an increase in extreme rainfall and an increase in flood episodes in the Batanghari Watershed. PRCPTOT and R99p are the extreme rainfall indices that have the most impact on floods in the Batanghari watershed [18]. If do not look at the statistics (significance criteria), in general the extreme rainfall indices has decreased. At Dago and Kayu Ambon stations, all indices show a decrease. At Lembang station, all indices show an increase, while at Tanjungsari 1 indices has decreased and 5 indices show an increase. So that all of the extreme rainfall indices analyzed at 4 rainfall stations there are 11 indices (55%) showing a decrease and 9 indices (45%) showing an increase. Research conducted by [19], regarding the impact of climate change on flooding and extreme rainfall shows that globally, dry and semi-arid areas are projected to expand, while humid and semi-humid areas are expected to decrease in coverage by the end of the twenty-first century. This is consistent with this study which shows that in the Cikapundung watershed from the 4 rainfall stations analyzed, most of the extreme rainfall indices show a decrease which means it will be drier than previous years.

These results suggest that the increase in the incidence or extent of flooding occurring in the Cikapundung watershed may not only be caused by an increase in extreme rainfall alone, but by other factors that need further investigation. For example, intensive land use change

in the area due to massive urbanization. With this urbanization, a lot of open land becomes impermeable so that when it rains, it becomes runoff. In addition, urbanization has also led to the construction of illegal buildings on either side of the river, narrowing the river channel and making it easier for flooding to occur. Therefore, it is necessary to analyze land use. This analysis is critical to understanding the capacity of the watershed to manage drainage and water absorption, which directly impacts flood risk [20].

4 Conclusions

Based on the analysis of extreme rainfall trends in the Cikapundung Watershed, most extreme rainfall indices do not show a significant trend, either increasing or decreasing. Only the Rx5day index at the Kayu Ambon station shows a significant downward trend. In general, 55% of the indices showed a decrease, while the other 45% showed an increase, indicating a trend towards drier conditions

Acknowledgement

This study is supported by DIPA Rumah Program Kebencanaan Hidrometeorologi, Organisasi Riset Kebumihan dan Maritim, BRIN and Pusat Riset Limnologi dan Sumberdaya Air, BRIN.

References

1. M. Azizah, A. Subiyanto, S. Triutomo, D. Wahyuni, Pengaruh perubahan iklim terhadap bencana hidrometeorologi di Kecamatan Cisarua - Kabupaten Bogor, *PENDIPA J. Sci. Educ.* **6**, 541–546 (2022)
2. T. Dyah, P. Pinuji, Ikhwanudin, Mitigasi bencana pada bencana hidrometeorologi di Indonesia, *Sci. Eng. Natl. Semin. 8 (SENS 8)* **8**, 144–148 (2023).
3. S. K. Allen, P. Rastner, M. Arora, C. Huggel, M. Stoffel, Lake outburst and debris flow disaster at Kedarnath, June 2013: hydrometeorological triggering and topographic predisposition, *Landslides* **13**, 1479–1491 (2016)
4. H. Wu, M. Huang, Q. Tang, D. B. Kirschbaum, P. Ward, Hydrometeorological hazards: monitoring, forecasting, risk assessment, and socioeconomic responses, *Adv. Meteorol.* **2016**, 11–13 (2016)
5. CRED, Annual disaster statistical review. The numbers and trends, *Proc. Annu. Hawaii Int. Conf. Syst. Sci.* **2002-Janua**, 1060–1069 (2007)
6. M. L. Mubarokah, P. Kurniati, Banjir menerjang Bandung Selatan, 3 Kecamatan terendam luapan Sungai Citarum, [Online], 2022. Available: <https://bandung.kompas.com/read/2022/04/24/162434278/banjir-menerjang-bandung-selatan-3-kecamatan-terendam-luapan-sungai-citarum?page=all>
7. E. Aguilar, I. Auer, M. Brunet, T. C. Peterson, J. Wieringa, Coordinator of text: Enric Aguilar, Contributions by: Enric Aguilar, Inge Auer, Manola Brunet, Thomas C. Peterson, and Jon Wieringa, Edited by: Paul Llansó, *World Meteorol. Organ.* **1186**, 52 (2003)
8. J. B. Wijngaard, A. M. G. Klein Tank, G. P. Können, Homogeneity of 20th century European daily temperature and precipitation series, *Int. J. Climatol.* **23**, 679–692 (2003)
9. C. K. Chang, A. A. Ghani, M. A. Othman, Homogeneity testing and trends analysis in long-term rainfall data for Sungai Pahang River Basin over 40 years records, 37th IAHR World Congr. **37**, 4197–4203 (2017)

10. M. G. Donat, L. V. Alexander, H. Yang, I. Durre, R. Vose, J. Caesar, Global land-based datasets for monitoring climatic extremes, *Bull. Am. Meteorol. Soc.* **94**, 997–1006 (2013)
11. X. Zhang, Indices for monitoring changes in extremes based on daily temperature and precipitation data, *Wiley Interdiscip. Rev. Clim. Chang.* **2**, 851–870 (2011)
12. R. Lorenz, Representation of climate extreme indices in the ACCESS1.3b coupled atmosphere-land surface model, *Geosci. Model Dev.* **7**, 545–567 (2014)
13. Misnawati, M. Perdanawanti, Trend of extreme precipitation over Sumatera Island for 1981–2010, *Agromet* **33**, 41–51 (2019)
14. J. Suhaila, S. M. Deni, A. A. Jemain, Detecting inhomogeneity of rainfall series in Peninsular Malaysia, *Asia-Pacific J. Atmos. Sci.* **44**, 369–380 (2008)
15. G. M. Tsidu, High-resolution monthly rainfall database for Ethiopia: Homogenization, reconstruction, and gridding, *J. Clim.* **25**, 8422–8443 (2012)
16. Supari, F. Tangang, L. Juneng, E. Aldrian, Observed changes in extreme temperature and precipitation over Indonesia, *Int. J. Climatol.* **37**, 1979–1997 (2017)
17. A. N. A. J. Fura, R. U. A. Wiyono, I. Indarto, Kecenderungan dan perubahan hujan ekstrem harian di Pulau Madura, *J. Ilmu Lingkungan.* **18**, 89–96 (2020)
18. U. Handoko, R. Boer, E. Aldrian, Misnawati, B. D. Dasanto, Apip, Effect of climate change on the characteristic of extreme rainfall over Batanghari watershed, *IOP Conf. Ser. Earth Environ. Sci.* **1314**, 1 (2024)
19. H. Tabari, Climate change impact on flood and extreme precipitation increases with water availability, *Sci. Rep.* **10**, 1–10 (2020)
20. H. Hendrayana, I. A. Riyanto, A. Nuha, Ruslisan, Multi-parameter approach to determine the floods causes in North Luwu, South Sulawesi, *IOP Conf. Ser. Earth Environ. Sci.* **1378**, 1 (2024)